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Marten Fur Harvests and Landscape Change in West-Central Alberta

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ABSTRACT Trapping for furbearers remains an important outdoor activity in Alberta, Canada, despite low fur prices and extensive industrial development. We investigated the influence of landscape change on furbearer harvests using 30 years of marten (*Martes americana*) harvest records, interviews with trappers, and Geographic Information System maps of industrial activity and vegetation types. We used an information-theoretic approach to explore variation in trapper success. Cover type and landscape metrics apparently influenced trapper success, because traplines where martens were consistently caught had less vehicle and all-terrain vehicle access, fewer oil and gas wells, and greater proportion of mature conifer forests than traplines where martens were infrequently caught. We identified an important cutoff value or statistical threshold that identified 45% closed-conifer cover, suggesting that a minimum amount of forest cover is crucial for trappers to catch martens. We conclude that the nature and extent of industrial disturbance is contributing to the decision by trappers to trap as well as influencing their success. We recommend that wildlife managers collect trapping effort information (i.e., species-specific no. of trap-nights) on fur reports in association with landscape changes to monitor furbearer harvests more effectively. (JOURNAL OF WILDLIFE MANAGEMENT 73(6):894–903; 2009)

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KEY WORDS Alberta, development, forestry, furbearers, harvesting, landscape change, marten, *Martes americana*, oil and gas, trapping.

Trapping for furbearers remains an important outdoor activity in Alberta, Canada, despite low fur prices and extensive industrial development (Barrus et al. 1997). Observations and harvests by trappers have been instrumental in the management of furbearers. Biologists have used harvest records to help monitor furbearer relative abundance (Smith and Brisbin 1984), adjust harvest quotas (Fryxell et al. 2001), estimate population densities (Fryxell et al. 1999, Cattadori et al. 2003), examine cyclic fluctuations (Erb et al. 2001, Viljugrein et al. 2001), evaluate status and distribution (Erickson 1982), collect biological information (Strickland and Douglas 1987, Simon et al. 1999), and assess effects of trapping and forestry practices on furbearers (Quick 1956, Payer 1999). Although there have been several initiatives to analyze furbearer harvest trends regionally or provincially (Boyd 1977, Skinner and Todd 1988, Poole and Mowat 2001), no research has examined variation in fur harvests as a function of land use and landscape change at the scale of registered traplines. Therefore, we examined patterns in long-term fur harvests and trapline status as they relate to industrial development and other landscape changes on registered traplines in western Alberta.

Documenting effects of changes in habitats is becoming increasingly important as landscape fragmentation and isolation continue to be major threats particularly for forest-dependent wildlife (McAlpine et al. 2006). Marten (*Martes americana*) have been considered an ecological indicator or barometer of forests composed of vertical and horizontal structural complexity (e.g., canopy cover, snags, and down woody debris; Koehler et al. 1975, Buskirk and Ruggiero 1994, Lee and Hanus 1998, McLaren et al. 1998). Large spatial requirements, narrow habitat use, longevity, low reproductive output, sensitivity to habitat loss, and vulnerability to trapping highlight the importance of monitoring marten (Archibald and Jessup 1984, Buskirk 1992, Smith and Schaefer 2002).

Declines of marten populations have been attributed to human activities, with overtrapping and habitat loss the most significant causes (de Vos 1952, Strickland and Douglas 1987). Previous research has focused on the response of martens to timber harvesting, the primary cause of habitat loss (Thompson 1994, Chapin et al. 1997, Huggard 1999). Timber harvest reduced suitable habitat and decreased population productivity in northern Maine, USA, based on comparisons of an untrapped reserve to a trapped and untrapped industrial forest (Payer 1999). In untrapped reserves without timber development, martens had higher survival and an older age structure (Fortin and Cantin 1994, Thompson 1994), occupied all available habitats (i.e., habitat saturation), had smaller home ranges, and density of lactating females was 3 times greater than in industrial untrapped forests (Payer 1999). In Quebec, Canada, Potvin and Breton (1997) studied short-term effects of clear-cutting on martens in the absence of recreational trapping and found lower survival, larger home ranges, and longer movements in cutover forests. Thus, it is clear that marten populations may be limited by timber harvest; however, this association has not been explored using marten trapping records.

Timber harvest and oil and gas exploration, as well as associated infrastructure of roads, generate most of the human footprint in Alberta's forests (Schneider 2002). The relationship between marten harvests and industrial development, in the form of roads and trails, oil and gas wells,

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and forest cutting, are not well studied. Based on previous research, we would assume that openings like well sites and clear-cuts would have a negative influence on marten harvests because of reduced marten density (Bissonette et al. 1989). But access, such as roads, pipelines, and all-terrain vehicle (ATV) trails, could have varied effects on marten harvest patterns. Seismic exploration trails (2–6 m wide) create openings in the forest canopy and unburned tree slash from trail clearing could improve subnivean access for marten hunting small mammals (Corn and Raphael 1992). But increased access also allows trappers to increase their effort distributing traps over a larger area, thus increasing probability of martens being caught (Marshall 1951). Conversely, wide roads and pipelines increase habitat fragmentation and create dispersal or movement barriers (Reed et al. 1996, Marklevitz 2003). Robitaille and Aubry (2000) studied frequency of occurrence and number of marten tracks in relation to roads and found significantly fewer marten tracks near roads as compared to transects further from roads. Given the complexity, examining the relationship between marten trapping records and land use covariates might help to reveal patterns of variation in trapper success.

Research has found that martens are more abundant in undisturbed forests with large core areas and avoid landscapes composed of >25% openings (Snyder and Bissonette 1987, Bissonette et al. 1989, Hargis and Bissonette 1997). Fahrig (1997) concluded that habitat loss had a more pronounced effect on population persistence than habitat fragmentation, especially on forest-dependent interior species. Consequently, we would expect that the amount of good-quality habitat would be a key predictor for marten trapping success.

Unraveling fur-harvest patterns and their relationship to social and biological influences will enable wildlife managers to use trapping data more effectively. Long-term data from registered traplines in Canada provide researchers the opportunity to examine factors that influence trapping success. Therefore, our objectives were to 1) document the relationship between trapper success, forest cover, and land-use activities, 2) determine the influence of landscape change on changes in marten harvests, and 3) estimate effects of forest cover and land-use activities on number of martens harvested per unit area.

STUDY AREA

We studied registered traplines (i.e., trapping areas) in an intensively managed area (28,000 km^2) of the Rocky Mountain foothills of Alberta that encompassed 136 traplines (Fig. 1). The registered trapline system allowed individual trappers exclusive rights to harvest fur on provincial (Crown) lands. Traplines were polygons with anthropogenic (e.g., roads), political (e.g., national park), or natural (e.g., rivers, ridges) boundaries determined by Alberta Sustainable Resource Development (ASRD; Pybus 2005). Trappers were required to complete fur-harvest reports each year when renewing their trapping license to verify the number and composition of furbearers harvested the previous season. Trappers, however, were not required to report trapping effort (i.e., no. of trap-nights) or distribution of effort throughout the trapline (i.e., where traps were set) on fur reports.

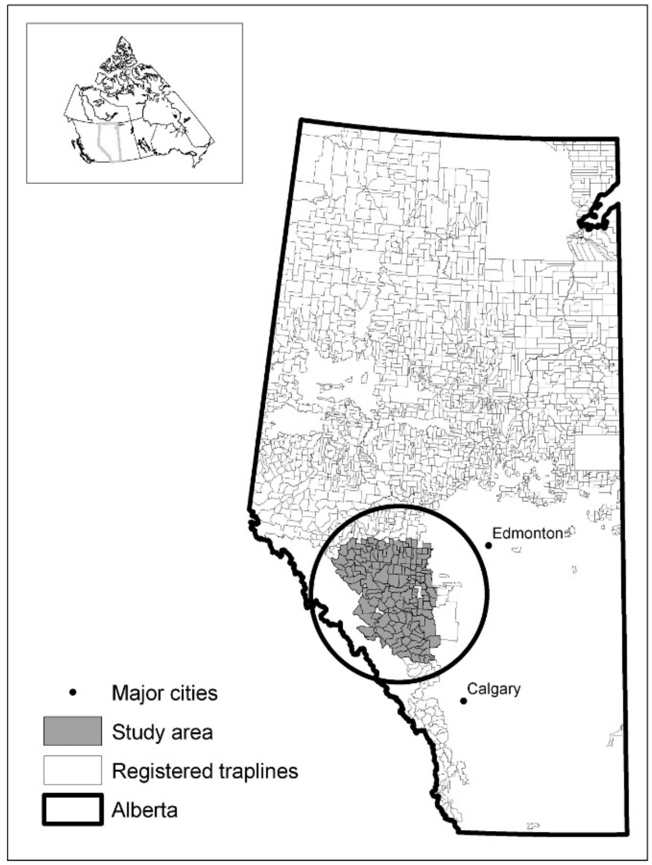

Figure 1. Study area map showing distribution of registered marten traplines on provincial crown lands in Alberta and the registered traplines studied from 1970 to 2003 in west-central Alberta, Canada.

Topography was rolling hills to mountainous terrain with elevation ranging between 700 m and 3,500 m. Dominant tree species included white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), larch (*Larix occidentalis*), and aspen (*Populus tremuloides*). The province managed this area primarily for resource extraction (e.g., petroleum, forestry, and mining) and outdoor recreation. Oil and gas development and timber extraction have increased over the past 3 decades (Timoney and Lee 2001), creating substantial access for hunters, trappers, and other user groups.

METHODS

Data Collection

We compiled marten harvests for each trapline from 1970 to 2003 from hard-copy fur reports in ASRD Fish & Wildlife offices. We verified harvest records by a telephone survey of current trapline owners (Webb et al. 2008). Hard-copy reports improved reliability of marten harvest records and were consistent with trapper memory recall. We also obtained legal land descriptions and a geo-referenced spatial layer of registered traplines (i.e., polygons) for the study area from ASRD. Due to high inter-annual variation, we quantified average marten harvest per time-period (e.g., 1970s [1970–1980], 1980s [1981–1991], and 1990s [1992–2003]) for each trapline.

The ASRD Data Distribution Branch provided spatial layers of landscape data including roads (lines), seismic exploration trails (lines), power lines (lines), pipelines (lines), railways (lines), well sites (points), and other facilities (e.g., gravel pits, coal mines, and gas plants; polygons). We acquired clear-cut data directly from forestry companies or from the Central East Slopes Wolf and Elk Study (CESWES) classified from 2003 satellite imagery (H. Beyer, University of Alberta, unpublished report). We quantified vegetation cover types (e.g., closed-conifer, mixed, deciduous) using 2003 satellite imagery from Foothills Model Forest (Franklin et al. 2001) and CESWES habitat layers (H. Beyer, unpublished report). We classified vegetation types for the 1990s only. However, we were interested in the amount of forest cover in earlier periods and closed-conifer was the dominant cover type in the study area (H. Beyer, unpublished report). We assumed that the area clear-cut in the 1980s and 1970s targeted closed-conifer cover (i.e., mature forest) to calculate amount of closed-conifer in earlier periods. We assessed fragmentation on each trapline using all landscape variables to calculate patch size (km^2, polygons) of remaining, unfragmented areas using the Subdivision Analysis extension for ArcView 3.x (Lang 2004). Patch size is inversely related to the amount of fragmentation. More intact areas (i.e., less fragmentation) will have larger patch sizes and less intact areas (i.e., more fragmentation) will have smaller patch sizes (Jaeger 2000). We summarized all layers by time-period (i.e., 1970s, 1980s, or 1990s) and used a Geographic Information System to estimate the proportion of trapline area for each of the spatial layers.

Models

We analyzed 3 sets of models with the following response variables: 1) active–inactive marten trapline status; 2) change in decadal-mean marten harvest; and 3) mean marten harvest per unit area. Development of all 3 sets of models included identification of candidate models based on a literature review of marten ecology and factors that might influence trapper effort. We log- or $\log_e$-transformed skewed variables to meet assumptions of normality and bivariate linearity. To avoid collinearity we examined Pearson's correlation coefficients between predictor covariates and did not include strongly correlated (i.e., $|r| > 0.7$) variables in the same model. We ranked candidate models based on lack of fit and the principle of parsimony using Akaike's Information Criterion (AIC; Burnham and Anderson 2002). We ranked models based on the smallest Akaike value and the AIC differences (Δ_i), which indicated how well each model compared to the top-ranked (i.e., best) model. Models with AIC differences of <10 have some support, whereas values <4 have substantial support (Burnham and Anderson 2002). We also calculated weight of evidence (w_i) to determine how likely each model was the best model given the data.

We used a Welch Modified *t*-test to compare the landscape composition of active and inactive marten traplines by time-period. We were specifically interested in marten harvests and excluded trapping records of other furbearers for this part of the analysis. We defined traplines with ≥ 5 years of reported marten harvests for each time-period (i.e., 1970s, 1980s, and 1990s) as active, whereas traplines with <5 years of reported marten harvests in each period were inactive. If marten harvests were reported <5 years in any given period or there was a period without harvests, then we considered the trapline inactive. We did not have information on traplines where trappers set traps but did not catch martens (i.e., fur reports only included no. of animals taken).

We used logistic regression to fit a priori candidate models to predict probability of active or inactive trapline status (Hosmer and Lemeshow 1989). We quantified all covariates so that they were proportional to trapline area (e.g., proportion clear-cut). Covariates in the model included $\log_e$ proportion area cut (lnCut), proportion cumulatively disturbed (Disturb), proportion closed-conifer cover (ClosCon), $\log_e$ density of well sites (lnWell; wells/km^2), access density (Access; km/km^2), patch size (PatchSiz; km^2), and $\log_e$ trapline area (lnTrapArea; km^2). Traplines were the unit of replication and we treated time-period as a dummy variable with the 1970s period as the reference baseline to examine whether number of active traplines differed across time.

To assess fit of the predicted logistic regression models we used the threshold-independent receiver operating characteristic (ROC) method to calculate area under the curve (Fielding and Bell 1997). The ROC method plots sensitivity (i.e., probability of a harvest when harvest occurred) against 1-specificity (i.e., probability of a harvest when no harvest occurred; Fielding and Bell 1997). The ROC values range between zero and one with values near 0.5 considered poor model accuracy, because correct classifications are essentially random, and values >0.7 specified good model accuracy (Swets 1988).

To identify a threshold value for closed-conifer, we predicted probability of a trapline being active where sensitivity and specificity values converged (i.e., probability-cutoff) for our top-ranked model (Liu et al. 2005). First we predicted our top model and used STATA (StataCorp, College Station, TX) commands (i.e., lsens, genprob(p) gensens(se) genspec(sp)) to predict values into a datasheet. Next we sorted by probability active (p) and determined at which p value sensitivity and specificity values converged. Then we predicted our top model, holding all the other variables constant at their mean value except for closed-conifer to determine at which value of conifer where probability active was equal to the cutoff value. At this probability-cutoff we were able to best predict active versus inactive trapline status.

We used linear regression to model the relationship between the change in logarithm of average marten harvest per unit area (logMar89) relative to the change in cover types and industrial activity from the 1980s to 1990s. We used AIC_c, corrected for small sample size ($n/K < 40$, where n = sample size and K = no. of parameters), to rank candidate models and examined weight of evidence (w_i) of the top models ($\Delta_i < 4$; Burnham and Anderson 2002). In addition, we calculated a Pearson's correlation coefficient to test the null hypothesis that there is no relationship between marten and other valuable furbearer pelt prices at time t and the change in marten harvests between time t and $t + 1$ and between time t and $t + 2$ during 1967–2003.

We used a paired 2-sample t-test to test for differences in average harvest per unit area on all traplines between the 1970s and 1990s time-periods. We also used linear regression to model marten harvest corrected for trapline area in the 1990s. Predictor variables included proportion of the trapline composed of different vegetation types (e.g., closed-conifer, shrub, and mixed), $\log_e$ proportion area clear-cut (lnCut), proportion area disturbed (Disturb), mean patch size (PatchSiz), $\log_e$ density of access (lnAccess), and $\log_e$ of density of oil and gas wells (lnWell). We also included the change in landscape covariates from the previous time-period to evaluate whether the increase in disturbance and change in forest cover type influenced number of martens harvested.

RESULTS

Access (i.e., roads, seismic exploration trails, and right-of-ways) on registered traplines ranged from 0.12 km/km^2 to 9.31 km/km^2 ($\bar{x}$ = 3.58, SD = 2.07) and oil and gas well densities were 0–6 wells/km^2 ($\bar{x}$ = 0.64, SD = 0.99). Proportion of a trapline clear-cut ranged between 0 and 0.43 ($\bar{x}$ = 0.08, SD = 0.09), whereas proportion of late-successional conifer forest varied between 0.07 and 0.78 ($\bar{x}$ = 0.41, SD = 0.17).

Active–Inactive Trapline Status

Exploratory analysis revealed considerable variability in number of traplines that were consistently active through time. Approximately half of all traplines reported marten harvests $\geq$2 years in each time-period (n = 79 traplines), whereas only 33% of all traplines (n = 45 traplines) reported marten harvests during $\geq$5 years for the 1970s, 1980s, and 1990s. We observed differences in land use, forest cover, and landscape change among traplines that were and were not active through time (Table 1). Active traplines had 32% more closed-conifer forest cover and were 30% larger in size than inactive traplines. Active traplines also had 60% less deciduous forest and open wetlands and 44% less treed wetlands than inactive traplines. During the 1990s period, active traplines had 25% less truck and trail access and 67% fewer oil and gas well sites, as well as 35% fewer new access features (i.e., increase in access from 1980s to 1990s) and half as many new oil and gas wells as compared to inactive traplines. Differences between active and inactive marten traplines for the 1980s were similar to those observed during the 1990s. Finally, during the 1970s, active traplines had 83% fewer well sites and similar amounts of access as inactive traplines (1970s access: inactive $\bar{x}$ = 1.72, SE = 0.09; active $\bar{x}$ = 1.66, SE = 0.12, P = 0.7).

Table 1. Significant[a] mean and standard error of landscape variables[b] measured on marten traplines[c] from 1970 to 2003 in west-central Alberta, Canada. Significance was determined using a 2-sample t-test.

	Trapline status					
	Inactive		Active			
Variable	$\bar{x}$	SE	$\bar{x}$	SE	t-statistic	P-value
Industry						
Access9	3.90	0.24	2.94	0.22	2.98	0.004
Access8	3.13	0.20	2.44	0.20	2.41	0.02
Access89	0.77	0.07	0.50	0.06	2.94	0.004
Access78	1.41	0.15	0.78	0.13	3.21	0.002
Well9	0.82	0.12	0.27	0.04	4.25	$\leq$0.001
Well8	0.49	0.09	0.12	0.03	3.83	$\leq$0.001
Well7	0.35	0.08	0.06	0.01	3.51	$\leq$0.001
Well89	0.33	0.04	0.15	0.02	4.19	$\leq$0.001
Well78	0.14	0.02	0.06	0.02	2.79	0.006
Vegetation						
ClosCon9	0.37	0.02	0.49	0.02	−4.12	$\leq$0.001
ClosCon8	0.40	0.02	0.51	0.02	−3.84	$\leq$0.001
ClosCon7	0.42	0.02	0.52	0.02	−3.39	$\leq$0.001
Decid9	0.05	0.01	0.02	0.01	3.61	0.02
OpenWet9	0.02	0.002	0.01	0.002	2.91	0.004
TreedWet9	0.09	0.01	0.05	0.01	2.94	0.004
TrapArea	182.7	11.7	237.7	19.9	−2.39	0.02

[a] Insignificant t-test comparisons are not shown.
[b] Access = cumulative amt of linear features such as roads, pipelines, power lines, and trails/unit area (km/km^2). Well = no. of oil and gas wells/unit area (no./km^2). ClosCon = proportion of closed-conifer forest with >50% canopy closure (Franklin et al. 2001; H. Beyer, University of Alberta, unpublished report). Decid = proportion of mature deciduous forest (>70% deciduous canopy closure; H. Beyer, unpublished report). OpenWet and TreedWet = proportion of open and treed wetlands, respectively. TrapArea = trapline size (km^2). The number after a variable implies the period that we measured each variable in or the decadal change (e.g., Access9 = access in 1990 period; Access89 = change in access from 1980 to 1990 period).
[c] Inactive trapline = <5-yr reported marten harvests/period (n = 91); active trapline = $\geq$5-yr reported marten harvests/period for all 3 periods (n = 45).

Top logistic regression models suggested that a number of disturbance features, forest cover, and trapline characteristics were important in predicting whether a trapline was active over time (Table 2). We found no traplines with consistent marten harvests through time that had <20% closed-conifer forest cover or >36% of the trapline developed. Traplines were more likely to be active if they had more closed-conifer cover but more logged area, fewer well sites, less access, and larger trapline areas (Table 2). Probability of a trapline being active, however, did not differ among time-periods (Table 2). Likelihood of a trapline being active was highest for traplines with an intermediate proportion of closed-conifer forests (Fig. 2). Our model, however, suggested a decline in probability of a trapline being active with >55% closed-conifer forest cover.

For the top-ranked model, the best prediction of whether a trapline was active or inactive occurred at the intersection of sensitivity and specificity curves (i.e., probability-cutoff threshold; Fig. 3). Holding all other variables in the model constant except for closed-conifer cover, we found that the probability-cutoff threshold (0.57) occurred where 45% of a trapline was mature-conifer forest. The probability-cutoff threshold is the point where prediction of active and inactive trapline status is maximized relative to closed-conifer cover

Table 2. The most parsimonious ($\Delta_i < 4$) logistic regression models that predict probability of active traplines ($\geq$5 yr of marten harvests/period) from 1970 to 2003 in west-central Alberta, Canada. We report variables in each model,[a] beta coefficients, standard errors, lower and upper 95% confidence intervals, area under the receiver operating curve (ROC), Akaike differences (Δ_i), and Akaike weights (w_i).

Model	Variable	Coeff.	SE	95% CI	ROC	Δ_i	w_i
1	Constant	−7.72	1.19	−10.05, −5.39	0.7	0.00	0.53
	X80	0.47	0.26	−0.04, 0.98			
	X90	0.36	0.26	−0.15, 0.87			
	ClosCon	11.84	3.39	5.2, 18.48			
	ClosCon^2	−11.57	3.60	−18.63, −4.81			
	lnTrapArea	0.98	0.19	0.61, 1.35			
2	Constant	0.16	0.58	−0.98, 1.3	0.67	1.96	0.22
	X80	0.54	0.27	0.01, 1.07			
	X90	0.39	0.30	−0.2, 0.98			
	lnCut	0.16	0.06	0.04, 0.28			
	Access	−0.05	0.09	−0.23, 0.13			
	lnWell	−0.30	0.08	−0.46, −0.14			
3	Constant	−6.19	1.32	−8.78, −3.59	0.72	3.04	0.12
	X80	0.45	0.22	−0.08, 0.98			
	X90	0.23	0.31	−0.37, 0.84			
	ClosCon	8.91	3.64	1.78, 16.03			
	ClosCon^2	−9.18	3.75	−16.53, −1.84			
	lnCut	0.12	0.06	−0.002, 0.24			
	lnWell	−0.15	0.08	−0.31, 0.01			
	lnTrapArea	0.89	0.20	0.49, 1.29			

[a] X80 and X90 are the 1980 and 1990 periods as compared to the 1970 period. ClosCon = proportion closed-conifer forest with >50% canopy closure (Franklin et al. 2001; H. Beyer, University of Alberta, unpublished report). TrapArea = trapline size (km^2). Cut = proportion clear-cut. Access = cumulative amt of linear features such as roads, pipelines, power lines, and trails/unit area (km/km^2). Well = no. of oil and gas wells/unit area (no./km^2).

(i.e., the value that minimizes errors of both omission and commission; Liu et al. 2005).

Change in Harvest

The top linear regression models that predicted the change in marten harvests between the 1980s and 1990s included the change in the proportion of area disturbed and cut, change in the density of access and oil and gas wells, and forest cover measured in the 1990s (Table 3). An increase in proportion of a trapline disturbed and cut was an important predictor for a decline in harvest and confidence intervals for coefficients associated with these covariates did not include

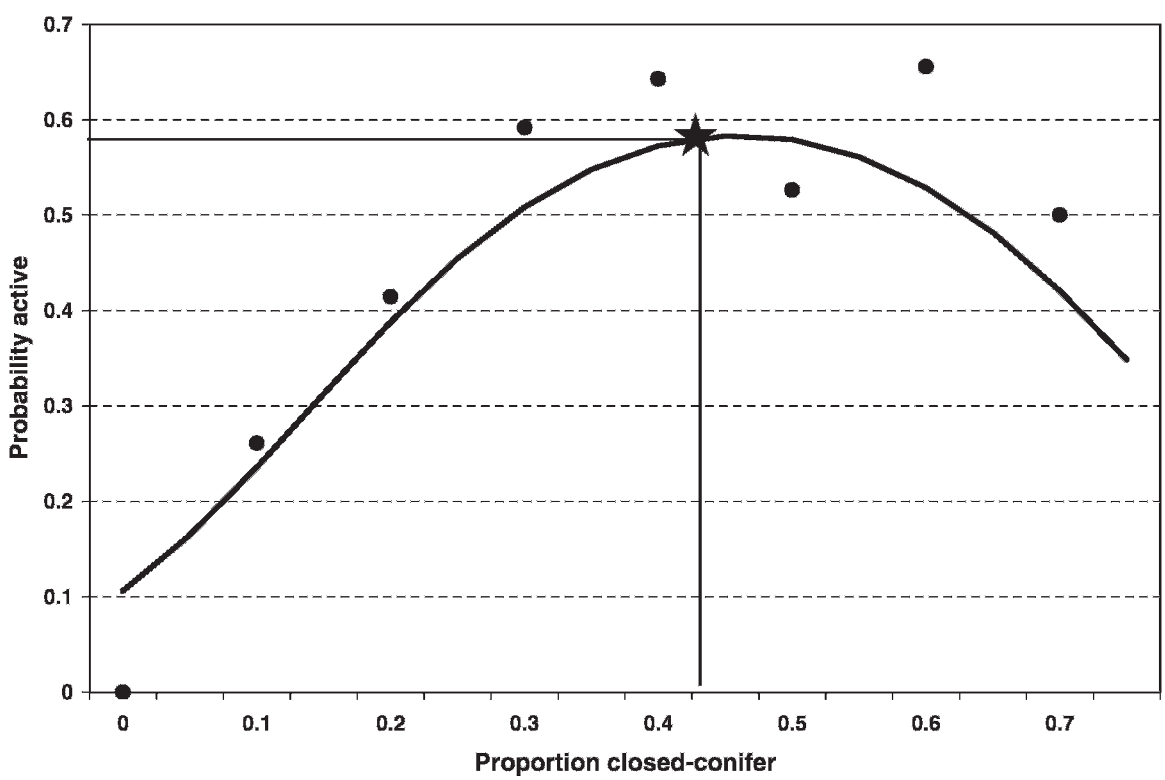

Figure 2. The relationship between predicted trapline status and closed-conifer forest cover (line) and the actual proportion of active traplines for martens within each pooled closed-conifer category (points) from 1970 to 2003 in west-central Alberta, Canada. A statistical threshold (star) occurs where approximately 45% of a trapline is composed of closed-conifer cover and the probability active equals 0.57.

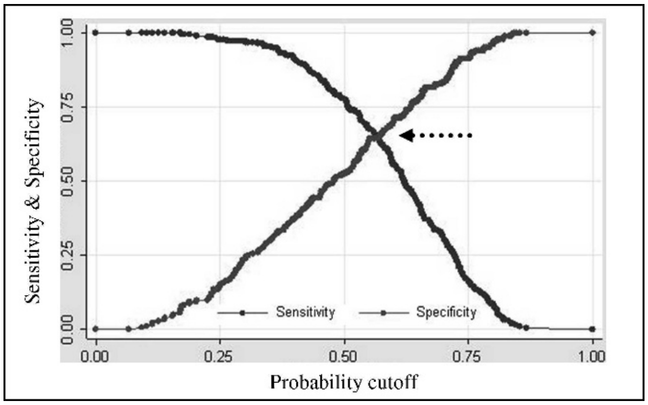

Figure 3. We evaluated the sensitivity and specificity curves of the top-ranked model used to predict probability of a trapline being active for martens from 1970 to 2003 in west-central Alberta, Canada. The intersection of the sensitivity and specificity curves illustrates a statistical threshold. Using the probability-cutoff of 0.57 (where the 2 curves meet) yields a threshold at approximately 45% closed-conifer cover. At this threshold, prediction of active and inactive traplines is maximized relative to closed conifer (i.e., the value that minimizes errors of both omission and commission).

Table 3. Top ($\Delta_i < 4$) linear regression models that predict change in average marten harvest per unit area from 1980 to 1990 period ($n = 136$) in west-central Alberta, Canada. We report variables in each model,[a] beta coefficients, standard errors, lower and upper 95% confidence intervals, Akaike differences (Δ_i), and Akaike weights (w_i).

Model	Variable	Coeff.	SE	95% CI	Δ_i	w_i
1	Constant	0.40	0.001	0.398, 0.402	0.00	0.42
	Disturb89	−0.02	0.01	−0.04, −4e − 4		
	Mix9	0.01	0.01	−0.01, 0.03		
2	Constant	0.50	0.02	0.46, 0.54	0.42	0.34
	ClosCon9	0.004	0.004	−0.004, 0.01		
	lnCut89	−0.04	0.02	−0.08, −8e − 4		
	Mix9	0.01	0.01	−0.01, 0.03		
3	Constant	0.50	0.02	0.46, 0.54	2.56	0.12
	lnCut89	−0.04	0.02	−0.08, −8e − 4		
	lnWell89	0.003	0.01	−0.02, 0.02		
	Access89	0.001	0.001	−9.6e − 4, 0.003		

[a] Disturb = proportion of cumulative land-base disturbed by oil and gas facilities, wells, access, and timber harvest. Mix = proportion of mixed deciduous and conifer forest cover. ClosCon = proportion of closed-conifer forest with >50% canopy closure (Franklin et al. 2001; H. Beyer, University of Alberta, unpublished report). Cut = proportion clear-cut. Well = no. of oil and gas wells/unit area (no./km^2). Access = cumulative amt of linear features such as roads, pipelines, power lines, and trails/unit area (km/km^2). The number after a variable implies the period that we measured each variable in or the decadal change (e.g., Mix9 = Mixed cover in 1990 period; Disturb89 = Change in cumulative disturbance from 1980 to 1990 period).

zero (Table 3). The top 2 models that included change in disturbance and forest cover had more support ($w_i = 0.42$) than change in disturbance alone ($w_i = 0.12$). Akaike weights for the top 2 models were similar (i.e., $w_i = 0.42$ and 0.34).

Marten harvests peaked in the late 1970s, before the peak in marten prices (Fig. 4). Marten harvests in our study area did not drop, however, despite declining pelt prices. The correlation between marten pelt price at time t and change in marten harvests between time t and $t + 1$ was −0.07 (35 df, $P > 0.05$) and between time t and $t + 2$ ($r = -0.2$, 34 df, $P > 0.05$) over the period 1967–2003. The correlation between number of martens harvested at time t and price at time t was 0.119 (36 df, $P > 0.05$). Similarly, there was no relationship between the sum in average coyote (*Canis latrans*) and lynx (*Lynx canadensis*) pelt prices at time t and change in marten harvests between time t and $t + 1$ ($r = 0.03$, 18 df, $P > 0.05$) or for the same variables between time t and $t + 2$ ($r = -0.39$, 18 df, $P > 0.05$), although sample sizes were small.

Harvest per Unit Area

Marten harvests fluctuated over time, with a sharp increase from 1970 ($\bar{x} = 100$) to 1979 ($\bar{x} = 1300$) but were more stable from 1980 to 2003 (range = 600–1,200 martens; Fig. 4). Approximately half of all traplines in the study area ($n = 65$) had an increase in average marten harvest/km^2 in the 1970s versus 1990s (1970s $\bar{x} = 0.03$, SE = 0.004; 1990s $\bar{x} = 0.05$, SE = 0.006; $t = 1.98$, 135 df, $P < 0.001$). The top model had a high weight of evidence ($w_i = 0.95$; Table 4). More martens were caught in areas composed of mixed-forest cover, increased closed-conifer forest cover (i.e., forest maturation from the previous period), and less open cover (e.g., shrub and treed wetland). Marten harvests were inversely related to the proportion cut, well density, and road and trail access density. Only the vegetation covariates did not include zero within confidence intervals, but it is evident that the interaction between vegetation cover and industrial development were important in explaining harvests because the vegetation-only model received a low weight of evidence ($w_i = 0.03$).

DISCUSSION

Despite the complexity of trapper behavior and fur-harvest dynamics (Webb et al. 2008), we found strong relationships between marten trapping success, industrial activity, and forest cover, with the patterns comparable to literature reports of high-quality marten habitats (Bissonette et al. 1989). We found no traplines with consistent marten harvests through time that had <20% closed-conifer forest cover or >36% of the trapline developed, indicating reduced trapping success associated with increased industrial activity or in areas with greater amounts of open cover. Inactive marten traplines had more truck and trail access and oil and gas wells than did active traplines. Given previous research on effects of forest harvesting on martens (Thompson 1994, Payer 1999), we were surprised that proportion clear-cut was not a strong predictor of trapline status or marten harvests. The positive association between active traplines and proportion cut could be attributed to 2 factors: 1) trappers capitalizing on expected spikes in short-term marten harvests from areas recently cut, or 2) forestry companies targeting their cutting in areas with more mature merchantable conifer forests. Contrary to northeastern Canada and United States, large-scale logging is new in Alberta. Partially led by the collapse of oil prices and government programs to diversify the economy in the 1980s, the rate of timber harvest in Alberta grew 5 times from the 1970s to 1980s (Schneider 2002). Approximately 4% of the study

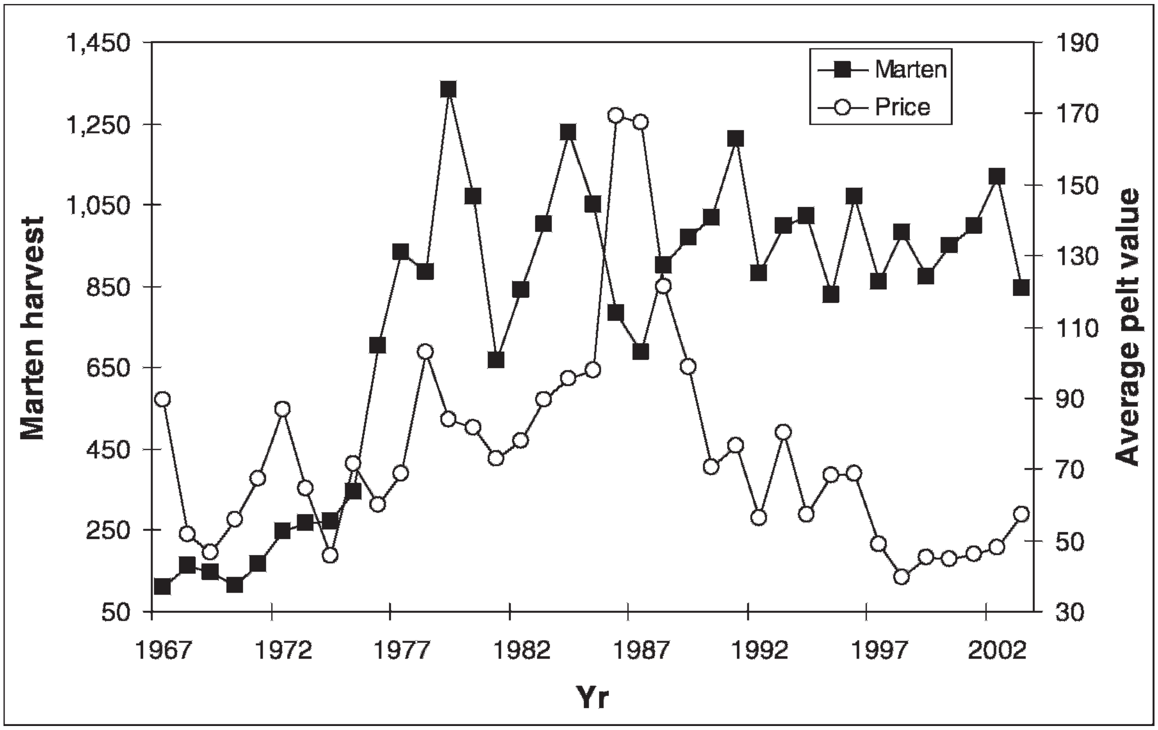

Figure 4. Reported marten harvests and adjusted (based on 2003 Canadian dollars) average pelt prices from 1967 to 2003 in west-central Alberta, Canada. Note that marten harvests were reported for the study area but pelt values were the average marten pelt value for Alberta (Statistics Canada 2002).

Table 4. Top ($\Delta_i < 10$) linear regression models that predict average marten harvest per unit area in the 1990 period ($n = 136$) in west-central Alberta, Canada. We report variables in each model,[a] beta coefficients, standard errors, lower and upper 95% confidence intervals, Akaike differences (Δ_i), and Akaike weights (w_i).

Model	Variable	Coeff.	SE	95% CI	Δ_i	w_i
1	Constant	0.54	0.02	0.5, 0.58	0.00	0.95
	lnCut89	−0.01	0.03	−0.07, 0.05		
	lnWell89	−0.01	0.01	−0.03, 0.01		
	Access89	−0.0003	0.001	−0.002, 0.002		
	lnshrub	−0.003	0.001	−0.005, −0.001		
	lntreedwet	−0.08	0.02	−0.12, −0.04		
	Mix	0.03	0.01	0.01, 0.05		
	Con89	0.02	0.01	4e − 4, 0.04		
2	Constant	0.53	0.02	0.49, 0.57	6.9	0.03
	Mix	0.02	0.01	4e − 4, 0.04		
	lnshrub	−0.003	0.002	−0.01, 9.2e − 4		
	lntreedwet	−0.10	0.03	−0.16, −0.04		
	lnbarren	−0.002	0.001	−0.004, −4e − 5		
	lnopencon	−0.002	0.002	−0.01, 0.002		
	logmodcon	0.004	0.004	−0.004, 0.01		
	logcloscon	−0.003	0.004	−0.01, 0.001		
	lnuplanherb	0.0003	0.001	−0.002, 0.002		
	lnregen	−0.01	0.02	−0.05, 0.03		
	Con89	0.02	0.01	4e − 4, 0.04		
3	Constant	0.47	0.003	0.46, 0.48	8.63	0.01
	lnPatchSiz	0.001	4e − 4	2.2e − 4, 0.002		
	ConPro9	0.02	0.01	4e − 4, 0.04		
	Mix	0.03	0.01	0.01, 0.05		

[a] Cut89, Con89, Well89, and Access89 = change in proportions of clear-cut and closed-conifer (50% canopy closure), new wells, and new access, respectively, from the 1980 to 1990 period. Shrub and treedwet = proportions shrub and treed wetlands, respectively. Mix = proportion of mixed deciduous and conifer forest cover. Barren = proportion of land that is bare soil or rock. Opencon, modcon, and closcon = proportions of conifer where canopy closure was open (<50%), moderate (50–70%), or closed (>70%), respectively (Franklin et al. 2001). Uplanherb = proportion of herbaceous, reclaimed herbaceous, and alpine–subalpine–wet meadow. Regen = proportion of young (<12 yr) burns and clear-cuts. PatchSiz = fragmentation metric used to describe the size of intact patches (km^2/km^2; Jaeger 2000). ConPro9 = proportion of closed-conifer forest cover (>50% canopy closure) measured in the 1990 period (Franklin et al. 2001; H. Beyer, University of Alberta, unpublished report).

area has been logged, which seems negligible. However, the total area of clear-cuts in our study area increased 35% (1970 to 1980 period) and 60% (1980 to 1990 period), indicating a substantial rise in forestry activities and enormous impact on some individual trapping areas.

Increased industrial development may provide jobs that replace trapping as a profession. But in large part, the expanding human footprint deters many recreational trappers (Webb et al. 2008) and results in reduced trapping success. Inactive traplines had a greater increase in new roads, trails, and wells, particularly during the 1980s and 1990s. In addition, fewer martens were caught on traplines with increased cumulative disturbance and proportion cut from the 1980s to 1990s. In our study area, roads and trails have doubled from the 1970s to 1990s. Road access has facilitated industrial and recreational activities and contributes to increased fragmentation. The greatest increase, however, has been creation of new well sites and facilities (e.g., gas plants), which have increased by 64% and 72%, respectively, from the 1970s to 1990s. Well sites and facilities are built on gravel pads typically devoid of vegetation and tend to leave long-term footprints on the landscape (Schneider 2002). Our results indicate that increased disturbance, particularly access and well sites, affect marten habitats and reduce trapper success. However, for trappers there is a fine line between having adequate access to maximize trapping efficiency and tolerable industrial activity on the landscape.

One of the most interesting findings was the importance of forest cover in predicting trapping success. We found that larger traplines with greater proportion of forest cover were important predictors for improving trapping success. Although researchers have determined that forest structure is a more important determinant of marten use than cover type (e.g., conifer, mixed, deciduous; Dumyahn et al. 2007), we found that closed-conifer forest had the strongest relationship of any vegetation type in explaining variation in trapper success. We used coarse cover types for our analysis because forest structure variables were difficult to measure over a large area and long time-period. Closed-conifer cover was either a proxy for high-quality marten habitats with abundant structure or was selected by trappers because of the perception that mature conifer forests yielded more martens (Barrus et al. 1997). We found that active traplines had greater amounts of closed-conifer forests in all time-periods and had less open cover (e.g., deciduous, open, and treed wetland) as compared with inactive traplines in the 1990s. Probability of a trapline being active increased until approximately half the trapline area was composed of closed-conifer. The decline in active trapline status above 55% closed-conifer was unexpected. However, traplines with 51–65% closed-conifer ($n = 8$) had a high change-over in ownership or trappers communicated personal reasons for not trapping in each period (Webb et al. 2008). Few traplines ($n = 6$) in our study had $\geq 70\%$ proportion of closed-conifer; those traplines that did and were inactive ($n = 3$) also had rugged terrain and limited road and trail access restraints as a result of low amounts of industrial disturbance, which might explain why trappers were less likely to catch marten. In general, many conifer-dominated traplines that were inactive were owned by aboriginal trappers and the number of aboriginal trappers has been declining in the province over the past decade (Poole and Mowat 2001). Thus, we believe that social factors were important determinants of trapline status, particularly in explaining why some traplines do not trap and catch marten at the upper end of conifer cover. Motivation to trap and adequate motorized access to marten habitats are critical components to trapping success.

We calculated an objective, statistical threshold that identified 45% closed-conifer cover, suggesting that a minimum amount of forest cover is crucial for trappers to catch martens. Fahrig (1997) found that population persistence was higher when the landscape was composed of $\geq 20\%$ breeding habitat for simulated organisms regardless of habitat fragmentation. This 20% habitat threshold also was important for forest habitat specialists such as the northern spotted owl (*Strix occidentalis caurina*; Lamberson et al. 1992). Hargis et al. (1999) determined that martens were in low abundance when the landscape comprised $>25\%$ nonforest cover even if connectivity was maintained. New research, however, suggests that martens will not establish home ranges unless $\geq 70\%$ of an area is suitable habitat (Dumyahn et al. 2007). The discrepancy in amount of suitable habitat is probably attributable to several factors. It is likely that an assortment of other vegetation types (e.g., mixed) with abundant cover and structure accounted for the additional amount of important habitat (i.e., up to 25% according to Dumyahn et al. [2007]) for martens. Although we measured proportion of conifer for each trapline, it is likely that the periphery marten habitats (i.e., on adjacent traplines) were important determinants of trapping success. Further study into configuration and composition of suitable habitat would be helpful in understanding threshold marten habitats.

Trapper harvest data can be valuable but must be used carefully. Much of our research focused on habitat factors, in part because they were quantifiable over a long time-period for each trapline. However, when analyzing fur-harvest data, managers must be aware of social factors, such as changes in economic conditions, increased access, improved technology, and management restrictions (i.e., seasons, quotas), all of which affect trapper effort (Webb et al. 2008). Although trapping participation has been declining in Alberta (Poole and Mowat 2001), we found that the number of active registered traplines in our study area remained constant through time (i.e., between 32 traplines and 41 traplines each period). The sharp increase in marten harvests in the 1970s was likely a result of forest maturation due to widespread fires in the early 1900s and subsequent fire suppression (Murphy et al. 2006), increased road and trail access primarily from oil and gas and forestry operations, and new technology (e.g., traps, ATVs, and snowmachines), which greatly improve trapping efficiency and success. Today, trapping is often weekend recreation rather than a full-time job (Pybus 2005), which might involve decreases in trapping effort. Although there have been shifts in socioeconomics, trapping technology, and access from 1970 to 2003, we suggest that sometimes these factors balance each other. For instance, increased access or use of better equipment can compensate for decreased trapping effort. Factors that influence fur harvests can be complex and difficult to measure, but it is still important to track changes in trapper participation and success. We suspect much of the unaccounted variation in marten harvests to be a result of activities on adjacent traplines (e.g., increased logging, inactive trapper), personal factors (e.g., health problems, changes in trapline ownership, weather), and ultimately trapper effort (i.e., no. of trap-nights; Webb et al. 2008).

MANAGEMENT IMPLICATIONS

Long-term fur-harvest records from registered traplines were valuable for modeling the response of marten harvests to landscape change. Apparently marten populations are becoming more vulnerable as habitats shrink and trapping access increases. Maintaining suitable habitat to counterbalance increasing forest activities will be critical for ensuring healthy marten populations and sustainable fur harvesting. We suggest that forestry and energy companies reduce fragmentation by coordinating construction of new roads and leaving $\geq 45\%$ of a trapline or township in mature forest cover to maintain martens. We recommend that wildlife managers collect trapping effort information (i.e., species-specific no. of trap-nights) on fur reports in association with landscape changes to monitor furbearer harvests more effectively.

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